EFFECT OF WATER IN PIPE INSULATION

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INTRODUCTION

Designers of government buildings, utility systems, and specialized Federal facilities are required by the Federal Energy Management Improvement Act of 1988 and The Energy Policy Act of 1992 to know how much energy the projects use, and, to be within the limits set forth by these laws. Recent research on pipe insulation sponsored by the American Society of Refrigerating Air-Conditioning Engineers (ASHRAE) indicates that moisture or water in insulation can have a dramatic impact on the heat transfer rate (Chyu, 1997 references 1,2,3 & 4). Heating and cooling applications were investigated. Closed cell insulations previously were thought to be resistant to moisture penetration and performance degradation; however, ASHRAE's research shows that closed cell insulations absorbed water and showed a marked degradation in performance. In general, the insulations that absorbed water the fastest, also dried out fastest; however the drying times are much longer than previously thought. Construction contractors believe that insulation can be dried out relatively easily, and that wet insulation need not be replaced. These ASHRAE tests suggest that in actual buildings and in actual insulated piping systems, the parameters needed to dry the insulation usually are not present, and suggests that we will not be able to dry the insulation enough to return it to the original k-value with the tools and time available at the construction site. Before this research was performed, 100 percent saturated insulation was thought to perform about four times worse than dry insulation. This research shows the heat transfer rate of wet insulation can be as much as 185 times higher than dry insulation. Even with as little as 5-10% moisture, typical of what might be found at a construction site, the heat transfer rates will be at least double that of dry insulation. A rule of thumb is when the heat transfer rate of an existing buried underground heat distribution system becomes roughly four times more than the new system, it typically becomes life cycle cost effective to replace the system with a new one. These tests indicate that it is much more life cycle cost effective to replace damaged systems than previously thought.

INSULATION TYPES

Four different types of insulations were tested. The product labeled fiberglass is a product with the trade name FIBERGLASS SSL-II manufactured by Owens-Corning . The insulation referred to as mineral wool is a product with the trade name PAROC-BWT manufactured by PARTEK. The insulation referred to as cellular glass is a product with the trade name FOAMGLAS manufactured by Phittsburgh Corning. The polyurethane insulation tested was obtained from a section of conduit from a commercial water spread limiting system manufactured by Thermal Pipe Systems. For this test, the casing or outer jacket, was stripped off, and the polyurethane was removed and tested.

FIBERGLASS

The product labeled fiberglass is a product manufactured by Owens-Corning and is assigned the trade name FIBERGLASS SSL-II. This is not a closed cell insulation. This is an off-the-shelf insulation that has not passed the 96 hour Federal Agency Committee boiling test. This insulation absorbed water faster than any of the other insulations tested. Both mineral wool and fiberglass use a glue called a binder to hold smaller sections of material together. If the binder is water soluble, or degrades when boiled, the insulation returns to smaller particles and ceases to function as an insulation. The binder used in this particular insulation was not identified, and, it held up well in this test. For a typical commercial grade fiberglass insulation, lacking the boiling test verification, we should expect the insulation to have a typical inexpensive binder and expect it to degrade into small particles if the insulation is boiled at high temperature for prolonged periods. This is what happens to most of the inexpensive commercial pipe insulations when they become submerged in water in the heating mode. Though low in first cost, the life cycle cost could be very high.

MINERAL WOOL

The mineral wool insulation tested is a product manufactured by PARTEK and is assigned the trade named PAROC-BWT. This is not a closed cell insulation. This product has passed the Federal Agency 96 hour boiling test. This product absorbed water much slower than the Owens Corning fiberglass product tested, and, is thought to have a binder that is resistant to high temperature boiling. This insulation has the lowest k-value of any of the insulations that have passed the 96 hour boiling test. It has a reasonably low first cost, and, usually projects the lowest life cycle cost when comparing to other insulation types. To compete in the life cycle analysis, other insulations have to be thicker and be priced less per unit volume.

CELLULAR GLASS

The cellular glass insulation tested and has the trade name FOAMGLAS, and is manufactured by Phittsburgh Corning. This insulation has passed the 96 hour Federal Agency Committee boiling test. FOAMGLAS is a closed cell insulation made of a material that allows very little moisture through the cell wall. FOAMGLAS has a relatively high k-value especially at mean temperatures above 150 C (302 F). This insulation behaves well in cooling applications, but, in heating applications, it cracks and compromises its closed-cell feature. When submerged in heating applications, the insulation cracked and let water reach the carrier pipe, which in turn become the main source of heat transfer. In the chilled water application, this insulation showed no degradation when submerged in water, and, performed like dry insulation.

POLYURETHANE

The polyurethane insulation tested was obtained from a section of a commercial water spread limiting system piping manufactured by Thermal Pipe Systems (TPS). The TPS conduit has a Class B Federal Agency Committee approval. The high temperature version of this product consists of a steel pipe, a layer of calcium silicate insulation, a space that is filled with factory blown-in polyurethane, and outer casing. All space between the carrier pipe and the casing is filled with insulation. For this test, the casing, or outer jacket, was stripped off, and the polyurethane was removed intact and became the test specimen. Since this polyurethane is a factory mixed and blown-in product, there is some variation in the density of the product which affects its k-value. Polyurethane insulation has not passed the Federal Agency Committee 96 hour boiling test, and, it is not intended for water submersion. The manufacturer's (TPS) design intends to isolate the polyurethane from ground water by keeping water out of the insulation cavity. However, due to errors in design, manufacturing and field assembly, water does reach the polyurethane on occasion, creating the necessity of a water submersion test. It appears that low temperature heat distribution systems will be more predominant in the future; therefore, polyurethane's water compatibility is of major interest.

CALCIUM SILICATE INSULATION

Calcium silicate insulation was not included in this testing simply because ASHRAE did not fund this work.

ADVERTISED PROPERTIES

In general, the heat transfer rates found in these tests for the tested insulations were 10% or more higher (worse) than the values advertised. ASTM-C-335, Test Method for Steady State Heat Transfer Properties of Horizontal Pipe Insulation, allows the test sample properties to vary 10 percent and still be considered a valid test specimen. The advertising people who prepare the advertising brochures apparently take this to mean that they can advertise values that are 10 percent better than the ASTM-C-335 tests indicate. This appears to be standard industry practice for pipe insulation.

CONCLUSION

The results of these tests run in the heating mode and the cooling mode are summarized in Table I. One of the most significant findings is that the heat transfer rate can increase up to 185 times when submerged in water. The heat transfer rate also increased in the cooling mode, but not as pronounced. This means that there is little doubt that it is Life Cycle Cost effective to replace a system with wet insulation. Boiling water near the pipe is the major source of the heat transfer in the heating mode. Even the closed cell insulations dramatically increased their heat transfer rates when submerged, 10 times for cellular glass and 17 times for the polyurethane. With as little as 10 percent moisture, the polyurethane heat transfer rate was double the dry value.

OPEN CELL INSULATIONS

The open cell insulations, the mineral wool and fiberglass, absorbed water quickly and became 99 percent saturated in as little as 30 minutes. These insulations had the highest heat transfer rates when wet, 50 and 185 times the dry rate respectively. These two insulations dried out quicker than the closed cell insulations; however it took as much as 9 days to completely dry.

CLOSED CELL INSULATIONS

The closed cell insulations, cellular glass and polyurethane foam, both absorbed water which caused the heat transfer rate to increase 10 and 17 times respectively in the heating mode. With 10 percent moisture in the polyurethane, the heat transfer rate was 2 times that of dry insulation. The polyurethane passed water through the cell walls, but the cellular glass did not. The cellular glass insulation cracked and passed water through the cracks in the heating mode. Water submersion affected the cellular glass very little in the cooling mode, where it performed as well as dry insulation. The polyurethane absorbed some water in the cooling mode and transferred heat at about twice the rate of dry insulation. The polyurethane took 50 days to dry in the heating mode.

SIGNIFICANT RESERVATION

One significant reservation that ASHRAE Technical Committee TC 6.2 had with respect to the data generated by these tests was that all of the insulations returned to within 5% their original k-values after being submerged in water and completely dried. This does not appear to agree with Federal Agency Committee field investigations. The Federal Agency Committee has investigated existing underground heat distributions systems at more than 200 sites. In each of these sites the system was excavated and opened up. The insulation was usually found to be degraded and in many cases it had actually disappeared from the carrier pipe to become a powder at the bottom of the casing. ASHRAE believes that there is at least one more parameter that these tests did not simulate. The submersion water in these tests was at or near atmospheric pressure, therefore never much higher than 100 C (212 F). In real distribution systems, the casing vents are sometimes closed which can cause a much higher temperature and pressure inside the casing, if there is water in the insulation. The boiling intensity in the real system could be significantly higher than the tests simulated here. Another possible answer might be that on the real sites, the contractor may have furnished an inexpensive insulation different from what the Federal Agency Committee approved. The approved insulations are not required to be factory marked. The insulations observed in the Federal Agency Committee excavations may have been an inexpensive commercial grade insulation.

APPLICATION TO BUILDING INSULATION

The effects of small amounts of moisture in insulation, in the 10 percent range, and the length of time to dry the insulation completely are two findings that we could apply to building insulations. We would expect that building insulations with as little as 10 percent moisture will transfer heat at 2 or 3 times the rate of dry insulation. Wet insulation will increase energy use significantly, and would cause a new building to exceed the Energy Budget. We should expect that it would take an extremely long time to dry installed insulation, to the point where we may have to consider it impractical to dry it in the field. The results of these tests suggest that those interested in how moisture degrades the properties of building insulation should investigate the information that ASHRAE has available on the subject.

REFERENCES

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TABLE I

INSULATION PERFORMANCE WHEN SUBMERGED IN WATER

	Mineral Wool	Fiberglass	Cellular Glass	Polyurethane
k-value of dry insulation	.03323 W/m*K (.0192) Btu/ft*h*F	.03738 W/m*K (.0216) Btu/ft*h*F	.04188 W/m*K (.0242) Btu/ft*h*F	.01956 W/m*K (.0113) Btu/ft*h*F
k-value (effective) of wet insulation - heating mode	1.7307 W/m*K (1.0) Btu/ft*h*F	6.9229 W/m*K (4.0) Btu/ft*h*F	.42403 W/m*K (.245) Btu/ft*h*F	.33403 W/m*K (.193) Btu/ft*h*F
k-value increase ratio	**50** heating mode	**185** heating mode	**10** heating mode	**17** heating mode
Time required for saturation - heating mode	2.5 hours to reach 99% saturated 10 days to 100%	30 minutes to reach 99 % saturated 2 hours to 100%	Cracks developed in less than 8 hours	70 days
Drying Time required for heating mode	9 days	6 days	8 hours	50 days
k-value increase ratio - cooling mode	**14** cooling mode	**20** cooling mode	**1.0** cooling mode	**2.0** cooling mode
Time required for saturation - cooling mode	6 days	7 days	less than 4 days	16 days
Time required for drying - cooling mode	25 days	55 days	8 days	10 days
k-value restored after drying	YES	YES	YES	YES